Report for 2004WI79B: Fate of Representative Fluoroquinolone, Macrolide, Sulfonamide and Tetracycline Antibiotics in Subsurface Environments

- Articles in Refereed Scientific Journals:
  - Gu, C.; Karthikeyan, K.G. Interaction of tetracycline with aluminum and iron hydrous oxides. Environ. Sci. Technol. 2005. 39:2660-2667.
  - Gao, J.; Pedersen, J.A. Adsorption of sulfonamide antimicrobial agents to clay minerals. Environ. Sci. Technol. (in revision).
  - Gu, C.; Karthikeyan, K.G. Sorption of the antimicrobial ciprofloxacin to aluminum and iron hydrous oxides. Environ. Sci. Technol. (in review submitted June 2005).

Report Follows

Fate Of Representative Fluoroquinolone, Macrolide, Sulfonamide and Tetracycline Antibiotics In Subsurface Environments

K. G. Karthikeyan, University of Wisconsin-Madison, Biological Systems Engineering
and
J. A. Pedersen, University of Wisconsin-Madison, Soil Science
Funding Agency: UWS Groundwater Research Program

Project Duration: July 2003–June 2005

Municipal wastewater treatment plant effluent and confined animal feeding operations represent important sources of antibiotics to the environment. The last few years have witnessed an increasing number of publications documenting the occurrence of antibiotics in surface waters and groundwater, heightening concern about their presence in the environment. Compared to conventional organic contaminants, little information is available on the environmental behavior of antibiotics. Our ability to predict mobility, fate and effects of antibiotics is hampered by a lack of information on fundamental processes governing their behavior in the environment. The overall goal of this project is to determine the extent to which association of antibiotics with particle-bound and dissolved natural organic matter influences their mobility in soils and subsurface environments. We intend to focus on representative antibiotics from four major classes: fluoroquinolones, macrolides, sulfonamides and tetracyclines. The selected antibiotics have been detected in wastewater influent and effluent in Wisconsin and in streams throughout the U.S. Our specific objectives are to: (1) quantify the extent of sorption of these antibiotics to humic substances associated with hydrous iron and aluminum oxides and smectitic clays; and (2) investigate antibiotic association with dissolved and particle-bound organic matter. Our research findings will help in assessing the ability of soils to act as potential sinks for these emerging organic contaminants and increase understanding of their environmental fate and transport characteristics as influenced by particle-bound and dissolved natural organic matter.

1. Year II Project Update:

This report summarizes our progress during the past year (Year II: July 2004 - June 2005) of our research project. The end date of the project is February 28, 2006.

I. Sorption of Antibiotics to Mineral Surfaces:

Prior to initiating sorption experiments with mineral-associated humic substances, we investigated the effect of solution chemistry on antibiotic sorption to the pure mineral phases. Association of tetracycline (TET) and ciprofloxacin (CIP) to hydrous oxides of Al (HAO) and Fe (HFO) and sorption of sulfamethazine (SMZ), sulfapyridine (SPY) and sulfamethoxazole (SMX) to smectitic and kaolinitic clays were investigated. In both the USGS national and our Wisconsin statewide surveys, TET, CIP, and SMX were among the most frequently detected antibiotic compounds.

In year I (2003-04), we completed the macroscopic experiments assessing solution chemistry (pH, ionic strength, sorbate-to-sorbent ratio) effects and reaction time on TET and CIP sorption to HAO and HFO. During the past year, complementary spectroscopic analysis (ATR-FTIR) was performed to elucidate the nature of CIP surface complexes formed on HAO and HFO. Results obtained from ATR-FTIR are indicative of the formation of different type of surface complexes with HAO and HFO; while a *monodentate mononuclear* complex (with the $-COO^-$ group) appears likely between CIP and HAO, the keto-O and one of the O from COO^- seem to be involved in the formation of a *six-member ring* with Fe on HFO surface.

In year I, we determined species-specific sorption coefficients (K_d values) for the association of SMZ with SWy-2, SAz-1 and GKa-1b. We also determined K_d values for SMZ sorption to Pahokee peat. During the past year we extended this work to examine the influence of surface charge density and the nature of the exchangeable cation on SMZ sorption to smectitic clay minerals. The effect of surface charge density was investigated by heat treating lithium exchanged clays to effect permanent charge reduction. Montmorillonite charge density influenced adsorption of the neutral and cationic species by determining adsorption domain size. Cation exchange appeared to contribute to adsorption of the cationic sulfonamide species to smectite surfaces. We also examined the effect of sulfonamide structure on sorption by obtaining sorption parameters for two additional sulfonamide antimicrobials: SPY and SMX. The nature of the sulfonamide R group influenced the degree of adsorption of the cationic and neutral species: cationic SMZ and SPY adsorbed to Na-SWy-2 to a larger extent than SMX. Our results highlight the importance of considering sulfonamide speciation and clay surface charge density in predicting the transport of these antimicrobials.

Our results and those of others indicate that hydrous oxides and clay minerals play an important role in influencing the environmental fate and reactivity of tetracycline and fluoroquinolone antibiotics. Sorption to clay mineral surfaces appears much less important for sulfonamide antimicrobials. Our research findings will increase understanding of the environmental fate and reactivity of these emerging organic contaminants.

II. Association of Antibiotics with Dissolved Organic Matter:

Sorption of SMZ, the macrolide clarithromycin (CLR), and TET to Elliott soil humic acid (ESHA) was investigated using the equilibrium dialysis method. Initial results indicate that CLR association with ESHA reaches a maximum between pH 6 and 7. The pH dependence of CLR sorption was likely attributable to changes in the charge and structure of ESHA and, to a lesser extent, CLR speciation. Clarithromycin is dominantly cationic below its pKa of 8.9 – 9.0. Similar pH dependence was observed for cationic quinilone-HA association. Association of SMZ with ESHA was strongly pH-dependent with K_{doc} increasing with decreasing pH.

Sorption equilibrium between TET and ESHA was attained in 24 h. However, a similar equilibration period was required for TET even in the absence of ESHA, which suggests that the rate-limiting step for the sorption process was antibiotic diffusion through the dialysis membrane. High compound recoveries (> 95%) were obtained indicative of negligible losses of TET due to sorption to the dialysis membrane. The experimental data will be described using the FITEQL 4.0 chemical equilibrium program to obtain complexation constants.

III. Association of Antibiotics with Humic-Coated Minerals:

We examined the sorption and desorption of three representative SMZ, SPY and SMX antibiotics to reference clay minerals with and without humic acid (HA) coatings. Coating clay minerals with HA enhanced sulfonamide sorption, and sorption increased with increased HA loading. Sorption of sulfonamide antimicrobials to humic-clay complexes was linear over the investigated concentration range. We are investigating the effect of HA loading and sorbent composition on sorption-desorption hysteresis.

2. **Notable Achievements and Awards**: Please report the title, date and description of any award, honor or recognition you or students associated with this project received related to this specific project.

3. **Publications:** Please provide us with a list of any publications resulting from this or related WRI-funded projects.

Gu, C.; Karthikeyan, K.G. Interaction of tetracycline with aluminum and iron hydrous oxides. *Environ. Sci. Technol*. **2005**. 39:2660-2667.

Gao, J.; Pedersen, J.A. Adsorption of sulfonamide antimicrobial agents to clay minerals. *Environ. Sci. Technol.* (in revision).

Gu, C.; Karthikeyan, K.G. Sorption of the antimicrobial ciprofloxacin to aluminum and iron hydrous oxides. *Environ. Sci. Technol*. (in review – submitted June 2005).